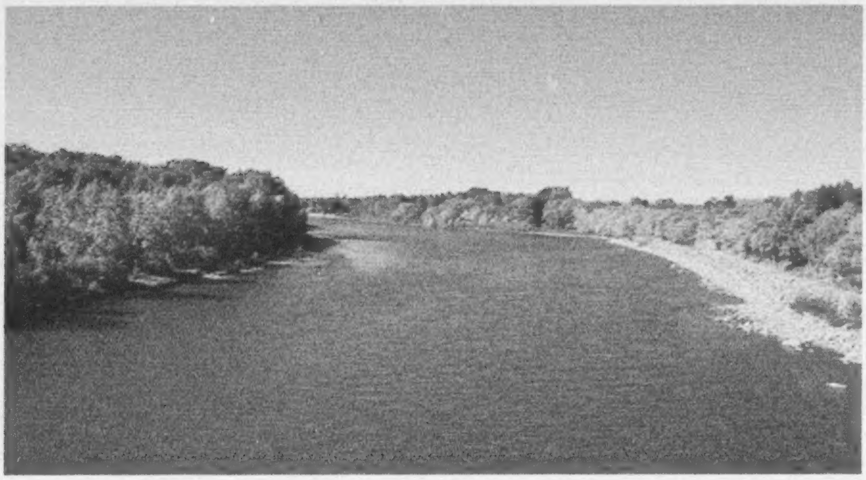
Alberta Government

Bow River Phosphorus Management Plan:

Water Quality Modeling Scenarios



ESRD Project Team
March 2014

Anish Neupane – Model scenario specification, coordination
Ping Wu – Flow input
Reza Ghanbarpour – Agriculture non-point source input
Nancy Martin – Instream water quality modeling

Executive Summary

Eight scenarios were run with the Bow River Water Quality Model (BRWQM) to support the Bow River Phosphorus Management Plan (PMP). The scenarios predicted close to 10% increase in the instream Total Phosphorus (TP) concentration above Highwood River using the loading projected by 2039. The Dissolved Oxygen (DO) was above the chronic guideline of 6.5 mg/L in all the scenarios; however, in some instances the DO was below 8.3 mg/L in May and June. The acute guideline showed two critical locations: 10 km downstream from Bonnybrook and 10 km downstream from Strathmore wastewater treatment plants (WWTP). The frequency of compliance was at or below 99.91% in these two locations for the scenarios that used the forecasted TP loading by 2039.

Copies of this report may be downloaded from:

Alberta Environment and Sustainable Resource Development
Website: www.esrd.alberta.ca and search "Bow River Phosphorus Management Plan"

Bow River Phosphorus Management Plan: Water Quality Modeling Scenarios, March 2014

ISBN 978-1-4601-1629-6 (Print)

ISBN 978-1-4601-1630-2 (PDF)

This report was prepared by Alberta Environment and Sustainable Resource Development for the Bow River Phosphorus Management Plan project.

Table of Contents

List of Figures

List of Tables

List of abbreviations

7Q10	the lowest 7-day average flow that occurs on average once every 10 years
BMPs	Best Management Practices
BRID	Bow River Irrigation District
BRWQM	Bow River Water Quality Model
CBOD	carbonaceous biochemical oxygen demand
CCME	Canadian Council of Ministers of the Environment
DO	Dissolved oxygen
ESRD	Environment and Sustainable Resource Development
PMP	Phosphorus Management Plan
RF	agricultural return flow
SSRP	South Saskatchewan Regional Plan
SWAT	Soil and Water Assessment Tool
TP	total phosphorus
WASP	Water Quality Analysis Simulation Program
WID	Western Irrigation District
WRMM	Water Resources Management Model
WWTP	Waste water treatment plant

Bow River PMP: Water Quality Modeling Scenarios

1. Background

The Bow River Phosphorus Management Plan (PMP) addresses the impact of phosphorus load in the middle reach of the Bow River – Bearspaw Dam to Bassano Dam (Appendix A). This reach supports diverse uses such as a majority of the basin population and industrial/commercial activities; significant agricultural land uses such as irrigation, dry land and livestock operations; and highly prized aesthetics and recreation opportunities. The PMP is a collaborative plan, involving all sectors that contribute phosphorus to the Bow River. The planning process was initiated by Alberta Environment and Sustainable Resource Development (ESRD) as a prototype for the implementation of a cumulative effects management approach in the southern region of Alberta. This prototype uses a number of tools to determine management actions that can be implemented to better manage the phosphorus loads to the Bow River. The Bow River Water Quality Model (BRWQM) was used to assess the effectiveness of some of those actions to manage the phosphorus loads, and to predict the river response to forecasted loadings to the river.

The organic materials measured as CBOD, and the nutrients (ammonia, nitrate and phosphorus) released from point and non-point sources can influence the aquatic vegetation, algae and dissolved oxygen concentrations in the Bow River. Water quality models are capable of predicting the temporal and spatial variability of different constituents in response to changes in flow, climate conditions, and the release of materials from point sources, storm sewers and tributaries. This is achieved by mathematically representing key physical, chemical and biological processes occurring in the river.

The BRWQM has been calibrated to ensure that model predicted results are within acceptable range of the observed conditions in the Bow River (Tetra Tech. 2013). Once the model is calibrated, it can be used to predict the change in concentration after changes in the loading to the river. Besides their predictive capabilities, water quality models usually have a high spatial and temporal resolution, which may be unfeasible in a long term monitoring network. These models divide the study reach into cells or segments, and each segment is assumed to have homogenous concentration of constituents (Appendix B). The BRWQM can simulate the water quality on average every 2 km, and provide the concentration at those locations every four hours. Because of the different advantages mentioned above, water quality models help to get a better understanding of the mechanisms and interactions that are behind an observed concentration and give a more defensible, credible and predictive framework that helps to evaluate management actions (Thomann and Muller.1987).

The BRWQM was originally developed to assist in obtaining a total loading management plan for The City of Calgary (Golder Associates. 2007). The model has been further enhanced and extended by ESRD, and its current geographic coverage is from Bearspaw Dam to Bassano Dam. This study area includes the discharge of seven main tributaries (Elbow River, Nose Creek, Fish

Creek, Pine Creek, Highwood River, West Arrowwood and Crowfoot Creek), five wastewater treatment plants (Bonnybrook, Fish Creek, Pine Creek, Heritage and Strathmore), several urban stormwater outfalls and agricultural return flows (RF). The BRWQM[1] consists of four sub-models as shown in Figure 1. The output from HEC-RAS, QHM and SWAT is used as input for the instream water quality mode WASP-MG.

Further application of the BRWQM includes informing planning decisions –e.g. interfacing with the water resources management model (WRMM) to evaluate changes in the water quality under different flow diversion and return flow conditions to inform the South Saskatchewan Regional Plan (Alberta Environment. 2010); examining the relative impacts on water quality in the Bow River as a result of varying phosphorus inputs and changing water diversion levels within the City of Calgary reach, and reduction in summer streamflows (Alberta Environment. 2011 [unpublished]).

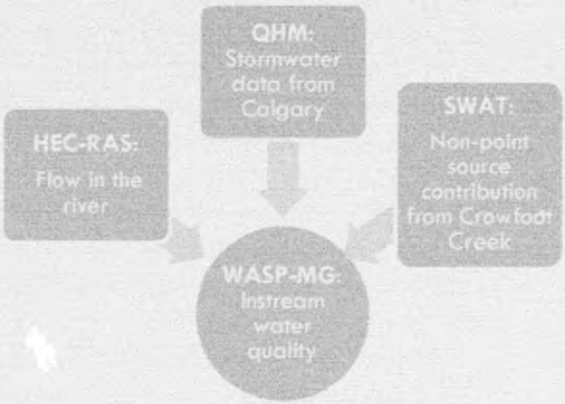


Figure 1. Bow River water quality model components

2. Scenario definition

The BRWQM was run for eight scenarios. The scenarios differed in the flow conditions and total phosphorus (TP) loading. The flow reflected changes due to climate change, changes in irrigation and municipal water demand, and reduction of irrigation return flow. The TP loadings were based on population projections at 2039, increase in City of Calgary stormwater, and the upgrades of Bonnybrook WWTP by 2020. The description for each scenario is presented in the following section and a summary is shown in Table 7.

Note that although the BRWQM is built with four components as shown in Figure 1, the main focus to date has been on the main stem and the application of watershed models has been limited to the Crowfoot Creek sub-basin. This focus to date has arisen due to the need to support regulatory decisions regarding load management on the main stem. However, water quality in the main stem is also affected by tributary sources[2] since the main stem is the receiving water body from these sources. The tributary and non-point sources do not have specific models that are part of BRWQM except for Crowfoot Creek. However, to a certain extent these sources have been accounted for when calibrating the BRWQM to the conditions of the Bow River using monitoring data. Specific to rural non-point, a SWAT model has been included in the BRWQM set

- [1] WASP 5.2 was modified to include algorithms governing macrophytes in the river.
- [2] These sources include non-point source and point sources that discharge onto tributaries.

up for Crowfoot Creek (Figure 1). Crowfoot Creek has been identified as a priority area to better understand the impact of agricultural non-point sources on water quality in past ESRD work. SWAT modelling output was included in the base case, reduced flow, and climate change scenarios. The PMP builds on that existing work by simulating some of the agricultural beneficial management practices (BMPs) identified by the rural non-point task team. A summary of BMP analysis results using the SWAT model are presented in a separate document in Appendix F. ESRD is currently investing in non-point source and tributary water quality models over the next few years that will cover high priority areas of the Bow basin. ESRD is also planning to build on this work and perform an assimilative capacity study on the Bow River focused on the impact of changes to loading conditions from different sources.

1. Base Case

The Base Case scenario was used to produce a base line ("business as usual" case) from which to compare the results of the other scenarios. This scenario represents current conditions (i.e. WWTP infrastructure, diversions and tributary water quality) superimposed on the streamflow and weather patterns from 1990 to 2007. These natural conditions can be projected in the scenarios looking to future conditions. Traditionally, modeling has been used to help on waste load allocation using two approaches: steady state with a worst case flow such as the 7Q10, or dynamic using the streamflow for a long period of time. The streamflow used for dynamic simulation includes a range of dry and wet years and the results can be assessed based on a frequency of compliance (Alberta Environment, 1995). Weather conditions with a range of warm and cool summers will also contribute to the predicted frequency of compliance.

The instream water quality observed in the '90s may not be representative of current conditions. The change in sampling frequency, land use and infrastructure may significantly affect the water quality estimated for the tributaries and background concentration. For example, the municipal effluent from High River was released to Highwood River and later moved to Frank Lake in the '90s. The instream water quality (background, Elbow, Nose and Fish Creek) was the monthly average concentration between 2004 and 2011 in the Base Case scenario to represent current conditions. This period aligns with the time range used by the PMP data analysis task (CPP and Hutchinson. 2013). Arrowwood Creek and Highwood River have a more limited number of recent samples than other tributaries. For these two tributaries, all the available samples after major changes to point source discharges were used to compute the monthly average (Table 1). The outliers were removed to calculate the TP concentration. These outliers were defined as a concentration higher than 1.5 times the inter-quartile range (average + 3 times the standard deviation). Concentrations reported below the detection limit were computed as half of the detection limit. The results from the non-point source model (SWAT) developed for Crowfoot Creek were used instead of using monthly means.

The stormwater loading was available for 1990-2007 from the QHM model developed by The City of Calgary. The City of Calgary is currently working on an enhanced stormwater model and their results can be integrated into the BRWQM when available. The BRWQM uses the direct loading coming to the Bow from stormwater outfalls; however, some urban runoff is also released into the Elbow, Nose, Fish and Pine Creek tributaries.

Table 1. Data extent for samples used to calculate inflow and tributary monthly averages

Inflow / Tributary	Time	Total samples used	Outliers
Bow River at Cochrane	2004-2011	96	0
Elbow	2004-2011	95	1
Nose	2004-2011	96	3
Fish	2004-2011	91	4
Highwood	2011- May 2013	23	1
Arrowwood	1995-1997 / 2004-2012	100	1

The year from 2008 to 2012 with the highest average TP concentration was selected to simulate the current point source loading to the Bow River (Table 2). This would mean that the water quality observed in the Base Case scenario is under a "worst-case scenario" regarding point source load. The average TP concentration for all the WWTPs was < 0.51 mg/L.

Table 2. WWTP effluent water quality selected for Base Case scenario

Plant	Effluent from year	Average TP (mg/L)	Average TP load (kg/day)	Data source
Bonnybrook	2008	0.51	180	daily concentration from monitoring database
Pine Creek	2011	0.21	13	daily concentration from monitoring database
Fish Creek	2012	0.49	17	monthly concentration estimated in annual report
Heritage Pointe	2009	0.37	0.25	monthly average concentration from annual report
Strathmore	2012	0.28	1.5	monthly average concentration from annual report

The irrigation water demand and return flow depend on the weather patterns, e.g. in dry years the diversions increase. The Base Case scenario used 2008 conditions, which represent an average year for BRID and WID in the 2004-2011period (Table 3). The effect of a dry year (2001) was assessed as one of the scenarios.

Table 3. WID and BRID water diversions and total allocation

Irrigation District	2008 water diversion (m^3/year)	Total allocation (m^3/year)	2001 water diversion (m^3/year)
WID	104,845,885	195,383,232	197,357,088
BRID	293,568,478	555,066,000	510,390,099

The municipal water demand depends on the population served. The diversion observed in 2011 was used to represent current conditions (Table 4), and the return flow was assumed as 80% of the diversion. The Okotoks water diversion forecasted by 2039 is higher than their annual

allocation. The Highwood River basin is closed for new licenses; as a result, the extra water required should come from transfers of unused water allocated in the basin, from groundwater or water transferred from another basin.

Table 4. Municipal water diversion and total allocation

Municipality	2011 water diversion (m^3/year) [ML/day]	Forecasted water diversion in 2039 (m^3/year) [ML/day]	Total allocation (m^3/year) [ML/day]
Calgary	181,318,495 [497]	296,840,680 [813.26]	460,184,000 [1,260.78]
Heritage Pointe	194,545 [0.53]	314,265 [0.86]	NA
Strathmore	1,320,570 [3.62]	2,059,695 [5.64]	2,659,000 [7.28]
Okotoks	2,654,280 [7.27]	4,518,700 [12.38]	2,766,000 [7.58]
Longview	59,130 [0.16]	63,875 [0.18]	NA
Black Diamond & Turner Valley	603,345 [1.65]	659,920 [1.81]	NA

2. Point source and stormwater load forecast

This scenario increased the point source and stormwater TP loading coming to the Bow River. The point sources discharged up to their loading objectives or projected loading by 2039 (Table 5).

Table 5. Municipal TP loading objective or projected loading by 2039

Wastewater treatment plant		Loading objective(*) or projected loading	
Calgary	Bonnybrook	234*	182
	Pine Creek		24
	Fish Creek		28
Heritage Pointe		1.2*	
Strathmore		5.2*	
Okotoks		3.94	
Longview		0.07	
Westend Regional Sewage Services		0.74	

Some wastewater sources have a loading objective that specifies the maximum daily annual average TP load that can be discharged. These loading objectives are as currently specified and assumed to remain unchanged into the future for the modelling purposes. Furthermore, for some sources such as The City of Calgary a modification was required since its loading objective of

340 kg/day includes both stormwater and wastewater loading. Of the total objective for Calgary, 240 kg/day was operationally assigned to wastewater; this assignment was confirmed in discussions with The City of Calgary as was the method to apportion this loading objective amongst the three Calgary wastewater plants. The model used value of 234 kg/day was considered to be very similar to operationally assigned value of 240 kg/day and is not expected to significantly alter the results. For the projected loading sources (ones that do not have loading objective) the loadings were the result of increase in wastewater flow from increased population for current water use level and TP removal technology.

The TP load for The City of Calgary WWTPs was estimated using the forecasted population growth (Bonnybrook with 264 ML/day at 0.51 mg/L and 235 ML/day at 0.2 mg/L; Pine Creek with 122 ML/day at 0.2 mg/L, Fish Creek at 57 ML/day at 0.49 mg/L). This produced a total City of Calgary point source load of 234 kg/day. The Okotoks, Longview and Westend Regional Sewage Services WWTPs discharge to the Sheep-Highwood sub-basin. A mass balance was performed for the Highwood River, which increased its concentration for this scenario. The municipalities diversion was modified to use the forecasted water diversion by 2039 (Table 4), and the return flow was again 80 % of the diverted water. Calgary's stormwater TP load was increased to 100 kg/day. The total stormwater was distributed in the different outflows discharging directly into the Bow River using similar proportions as in the Base Case scenario.

3. Technology Change

This scenario takes into account The City of Calgary's plans to upgrade the Bonnybrook WWTP by 2019/2020. A new train (Plant D) will expand the current treatment capacity by 100 ML/day. Plant D will include filtration, with an expected TP effluent concentration of 0.20 mg/L. The TP loading was calculated using the forecasted population served by Bonnybrook in 2020 and this concentration. This scenario assumes that the inflow coming to Bonnybrook will be first directed to Plant D, and the remaining influent will be treated in the current trains. The forecasted flows in 2020 and the projected TP loading are presented in Table 6.

Table 6. Water diversion, return flow, and TP loading projected by 2020 after plant upgrades

Calgary diversion (ML/day)	Return flow (ML/day)		TP Loading (kg/day)
657	Bonnybrook	394	170
	Pine Creek	88	18
	Fish Creek	54	21

4. Decreased summer inflows

Rood *et al.* (2005 and 2008) forecasted that the Bow River streamflow will decrease 10% from July to October by 2050 due to climate change. This scenario simulates the upstream boundary and tributaries inflows reduced by 10% during these months.

5. Increased diversion

This scenario simulates the effect of increasing the irrigation diversions to their full allocation, and The City of Calgary diversion to the volume forecasted by 2039 (Table 3 and Table 4). Additionally, the irrigation return flow was decreased by 50% compared to the Base Case scenario. The point source TP loading was calculated in two ways a) using the effluent coming back to the river and the Base Case concentration (assuming no technology change in the WWTPs); and b) using the forecasted load by 2039 or loading objective (Table 5).

6. Dry year diversion

Similar to Scenario 5, this dry year diversion scenario showed the impact of high irrigation water demand on the Bow River. Instead of using full allocation, this scenario used a high diversion year. The year selected was 2001 because this was a dry year. This high diversion was assessed under two TP loading conditions a) current (2011 loading), and b) forecasted loading by 2039 or loading objective. For the second option, it was also assumed a 50% reduction in the irrigation return flow.

Table 7. Summary of flow and TP conditions used in the scenarios[2]

Scenario		Streamflow	Irrigation	Point sources	Stormwater
Base Case		1990-2007	2008	2011 flow and concentration of the year with highest TP loading in 2008/11	QHM
Forecasted loading		BCS	BCS	Loading objective or forecasted loading by 2039.	100 kg/day
Technology change		BCS	BCS	Loading projected in 2020 after Bonnybrook expansion and upgrades	BCS
Reduced inflow		10% decrease July-October	BCS	BCS	BCS
High diversion	**without tech. change**	BCS	Full allocation, 50% decrease in RF	Loading objective or forecasted loading by 2039 without technology change.	BCS
	forecasted	BCS	Full allocation, 50% decrease in RF	Loading objective or forecasted loading by 2039.	BCS
Dry year diversion	**current**	BCS	2001 diversion	BCS	BCS
	forecasted	BCS	2001 diversion, 50% decrease in RF	Loading objective or forecasted loading by 2039.	BCS

[2] BCS indicates that the conditions are the same as the Base Case scenario

3. Input data used for the different scenarios

Base Case scenario representing current conditions

The Base Case scenario had a total TP load lower (35%) than the load used for model calibration in the 1990-2007 simulation period. The difference in load is mainly due to the WWTPs and Highwood River loading reductions under current conditions. The WWTPs have significantly improved their phosphorus treatment in the last decades. For the Highwood River, additional to the water quality improvement observed during this period, the loading reduction may be due to changing the method used to generate the input files. The TP was calculated after removing outliers and only considering samples from a few years (2011 - May 2013).

The total TP loading input in the Base Case scenario comes from different sources, background concentration, WWTPs, stormwater outfalls, irrigation return flows, and tributaries bringing point source as well as rural and urban non-point source loading. The contribution of each source varies significantly if analyzed by mean or median. The median tends to smooth the peaks observed during high runoff events producing lower loadings. Both the median and mean load distribution for the Bearspaw to Bassano reach are shown in Figure 2a, and 2b. A majority of the non-point source contribution comes from the high runoff events and for this reason the mean loading may be more conservative for tributaries. The proportion of the TP loading from each source changed seasonally for the Base Case scenario. The dissolved oxygen sags are more likely to happen in the open-water season, when the contribution from non-point sources increases (Figure 2c).

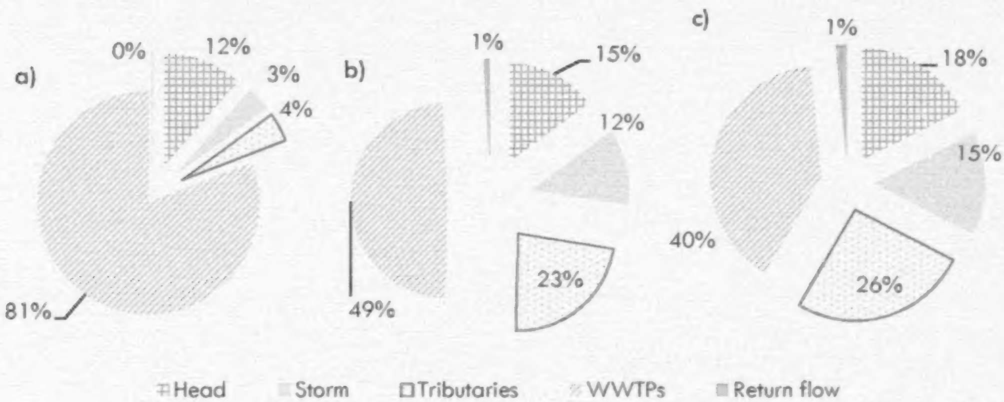


Figure 2. Total phosphorus load distribution in Base Case scenario Bearspaw to Bassano a) median and b) mean year-round, and c) mean load in the open-water season

Change in flow and loading from different scenarios

The assumptions and conditions set in the scenario definition represent different flow and loading coming into the Bow River (Table 7). Figure 3 shows the change in annual average flow at the most downstream segment (upstream Bassano Dam) and in the average daily TP loading relative to the Base Case scenario.

The Instream flow will affect the assimilative capacity of the river by diluting the pollutants, and influencing the oxygen transfer to the water. The change in the annual average flow was always less than 10% of the Base Case flow. Three ranges for the flow change were observed < 1.5%, 1.5-5%, and 5-10%. The flow was more significantly reduced by the High diversion scenarios (10%), and for the Dry year diversion scenarios and Reduced inflow (~4%). The TP loading varied more widely among the different scenarios. The load was most significantly changed for the High diversion without technology change and Forecasted loading scenarios. The TP contribution for each boundary condition in the model is presented in Figure 4.

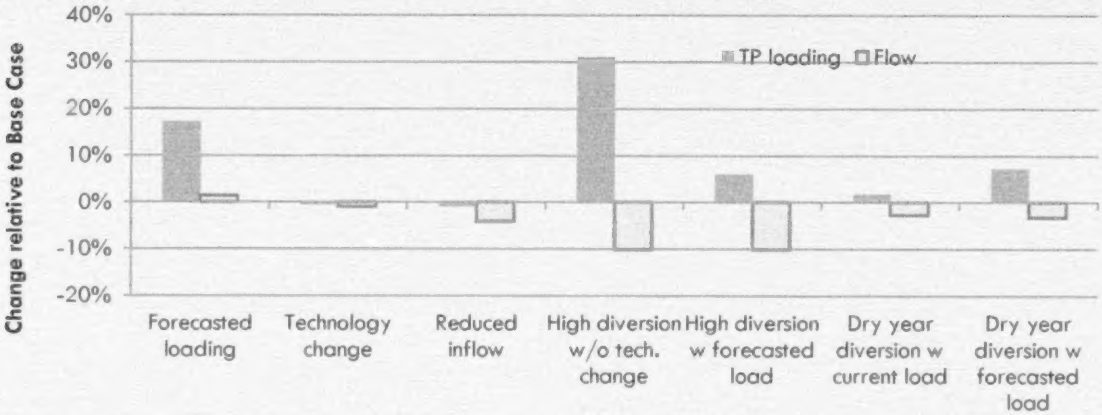


Figure 3. Change in the average flow at Bassano and average TP load relative to Base Case scenario

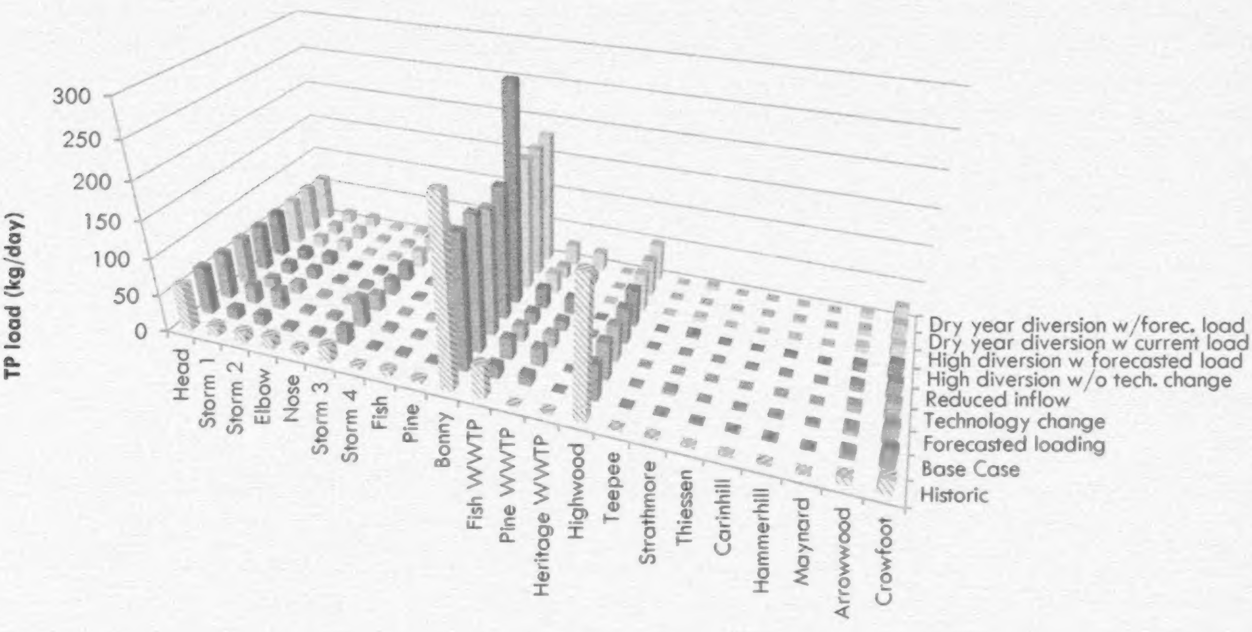


Figure 4. Mean phosphorus load from different sources in scenarios and historic 1990-2007

4. Results

The change in TP concentration and the dissolved oxygen compliance were analyzed for the different scenarios in the following section. First, the TP results for the Base Case scenario were compared with the observed mean and median (2004-2011). Then, the change in TP median from the current conditions (Base Case) was obtained for the simulated scenarios. Finally, the acute and chronic DO exceedances were analyzed.

The model provided output every 4 h during the 18 years simulated. This time interval reproduces the daily concentration pattern, and represents a large quantity of output data (>39,000 data points for each segment, each variable in each scenario).

A total of thirteen segments were selected for model output to analyze the water quality changes through the 200 km study reach (Table 8). These segments were selected at monitoring stations and downstream of the major point sources. The segments were not exactly at the discharge point or very close to it because the results are focused on far field (well mixed conditions) instead of near field analysis. Critical locations were identified and a more complete analysis was performed for those sections of the river where it is more likely to have non-compliance.

Table 8. Segments selected for model output and distance from first segment (Bearspaw Dam)

Id	Description	Approx. distance from Bearspaw Dam (Km)
1	3 km downstream of Bearspaw Dam	3
2	At Cushing Bridge	26
3	8 - 6 km downstream of Nose Creek and Elbow	30
4	10 km downstream of Bonnybrook WWTP	41
5	5 km downstream of Fish Creek WWTP	51
6	20 - 15 km downstream of Pine and Heritage WWTPs	70
7	10 km downstream of Highwood River	80
8	Below Carseland Dam	102
9	10 Km downstream Strathmore WWTP	108
10	Upstream Arrowwood River	142
11	10 Km downstream Arrowwood River	152
12	Cluny station	178
13	Upstream of Bassano Dam	210

Total Phosphorus concentration predicted in Base Case scenario

The Base Case scenario median and average TP concentrations at different stations are presented in Figure 5 for the open-water and ice cover seasons. This figure also shows the median and mean values

observed in 2004-2011. The objective of including observed values is to have a reference point on how the model is predicting the TP concentration along the river reach. The predicted values are not expected to be equal to the observed concentration because the model uses a hypothetical scenario as described in the previous sections. Additionally, the observed median is calculated using monthly grab samples, while the model provides output with a higher temporal resolution. Nevertheless, some level of agreement is expected as the Base Case scenario resembles current conditions. The model has already been calibrated for the period 1990-2007 to compare the agreement between observed and predicted values (Tetra Tech. 2013).

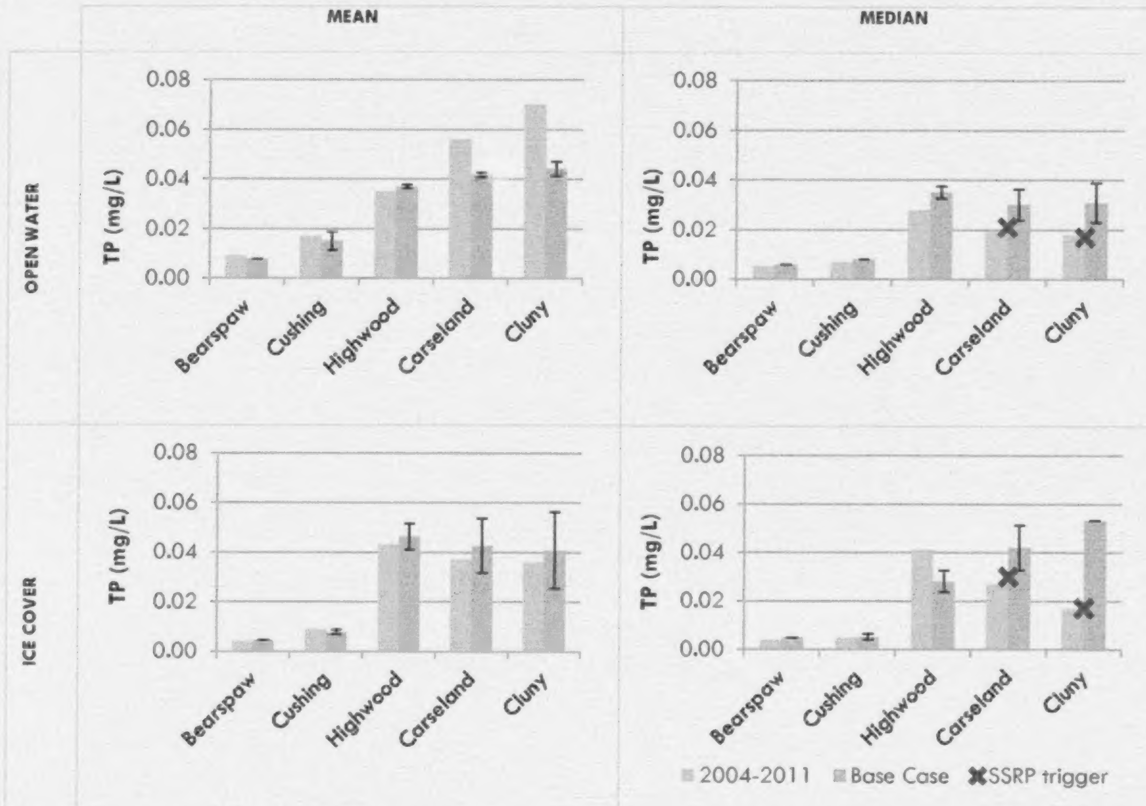


Figure 5. Seasonal mean and median TP predicted for the Base Case scenario and observed for the 2004-2011 period (the predicted values show an expected output range (bars) based on the calibration error)

The open-water season is the critical time when nutrients may promote high biomass growth having as a result dissolved oxygen sags before dawn. During the open-water season, the predicted values were close to the observed values following the overall trend. For the open-water period, the Base Case scenario predicted a median TP concentration at the meso-eutrophic trigger of 0.035 mg/L (CCME, 2004) above Highwood River for the eighteen years simulated. The median TP was below this trigger at the remaining stations. The median concentration predicted above Highwood was higher than the observed in the 2004-2011period, as the WWTP loading used in the Base Case scenario was calculated using a maximum TP concentration and the volume discharged to the river in 2011. The concentration

predicted in the Base Case scenario at Carseland was ~40% higher than the trigger defined in the SSRP of 0.021 mg/L for the open-water period (Government of Alberta, 2013).

Change in TP instream concentration for different scenarios

The ambient surface water quality triggers for the Bow River are defined in terms of median concentration in the South Saskatchewan Regional Plan (2013). For this reason, the change of median TP concentration was computed for each scenario. The scenarios were compared at the Above Highwood River station because this is where the highest concentration is usually observed. Additionally, the inter-site median TP was not significantly different in the open-water season for the sites from Highwood to Ronalane (CPP and Hutchinson. 2013, p.16). The change in TP was also analyzed at the Cluny station to take into account the cumulative loading in the downstream section of the study reach.

The TP change relative to the Base Case scenario is shown in Figure 6. Increasing the stormwater to 100 kg/day and the WWTP load up to the objective or 2039 projected load produced a 13% increase in the TP concentration above Highwood. The TP median concentration remained almost constant under the Technology change scenario. Although this scenario took into account the population projected by 2020, the Bonnybrook upgrades represented an overall reduction on the TP load released from this WWTP. The increase in TP load from Pine and Fish Creek WWTPs did not offset the reduction projected for Bonnybrook (Table 2 and Table 6).

The scenarios for which the flow was changed without change on TP load from point sources (Reduced inflow and Dry year diversion with current load) had a TP median concentration increase lower than 5% above Highwood River and at Cluny station (Figure 6). The TP did not change significantly under the climate change scenario; however, the cumulative effects could be significant. Additionally, this scenario did not take into account the changes in water demand under climate change conditions. The WID withdrawal in 2001 was very close to its total allocation (Table 3). As a result, the High diversion and Dry year scenarios with forecasted load produced similar TP median above Highwood.

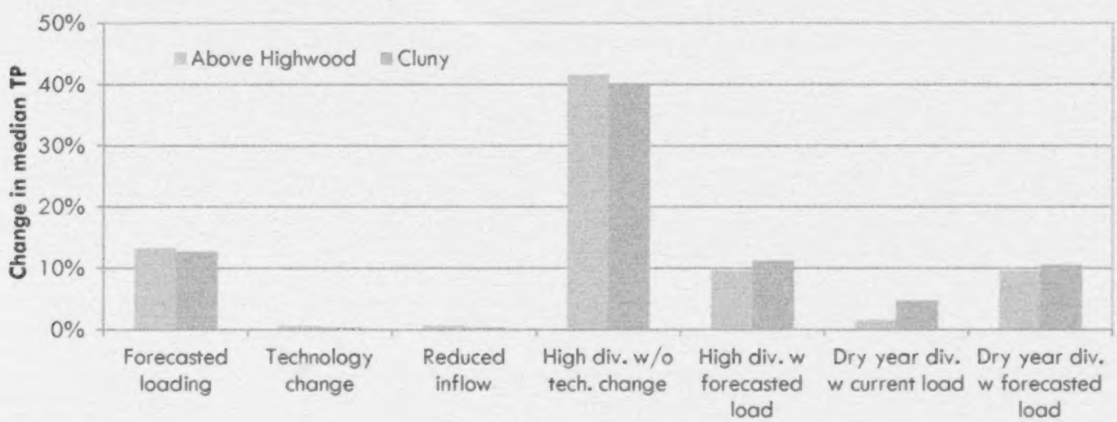


Figure 6. Change in TP median concentration relative to the Base Case scenario

The TP concentration would increase close to 40% if the diversions are increased to full allocation for irrigation and to the forecasted water use by 2039 for The City of Calgary without upgrades to the

existing WWTP technology (i.e. the same concentration from current infrastructure was applied to the forecasted return flow in 2039), and about 10% with technology change.

Dissolved oxygen in Base Case scenario

The DO guideline in Alberta is 5 mg/L (1-day min) for acute and 6.5 (7-day mean) for chronic exposure (AENV, 1999). The chronic guideline is increased to 8.3 mg/L from mid-May to the end of June to protect emergence of mayfly species into adults. The model predicted a macrophyte peak downstream Bonnybrook and a periphyton peak close to Carseland in the Base Case scenario. The longitudinal profile also predicted two valleys where the minimum DO reaches values below the acute guideline of 5 mg/L. The first valley starts downstream Bonnybrook; the DO concentration improves by Highwood River, and decreases again at Carseland.

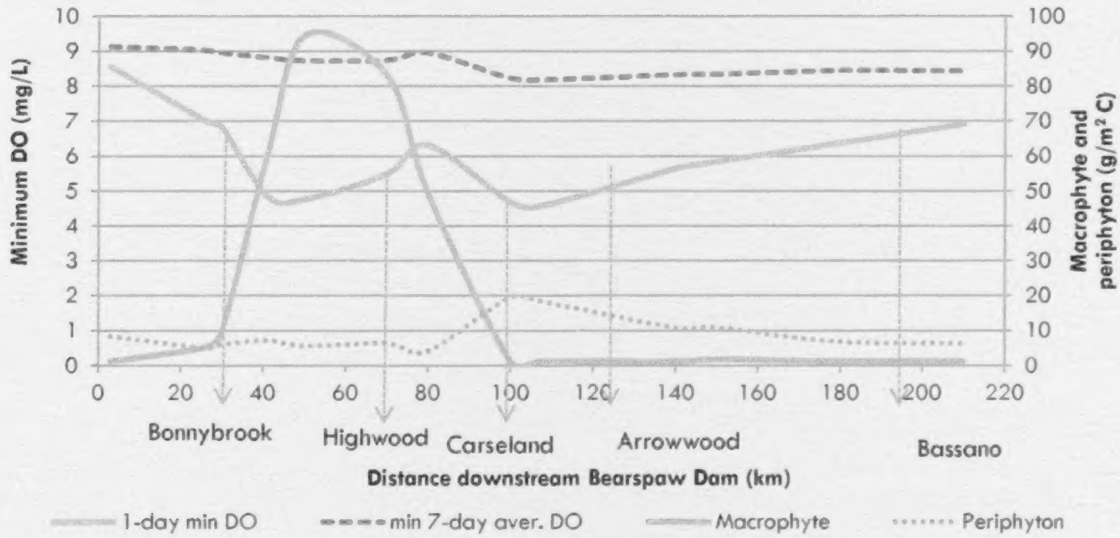


Figure 7. Periphyton, Macrophyte and minimum DO longitudinal profile for the Base Case scenario

The Base Case scenario predicted DO reaching minimum values below 5 mg/L for ~20 km in each critical area. The precision on the DO sag zone can be improved in the future by having more segments output in between these two critical areas. Please note that this graph does not include the frequency that the DO was predicted below the guideline, which is discussed below.

From the six data points output by the model each day (0, 4, 8, 12, 16, 20, 24 hrs.) the minimum DO was usually predicted at 4 am. The results assume that this was the 1-day minimum. The minimum DO observed in datasondes usually occurs between 3 and 6 am. The difference between the minimum DO and the DO observed at 4 am is most of the time < 5%. The frequency of compliance was calculated using the number of times the DO was below 5 mg/L and the number of days that the model was run (6574 days).

For the Base Case scenario, the frequency of compliance changed among locations from 99.88% to 100%. The compliance in most cases was above the recommended level of 99.91% (i.e. one exceedance

every three years) (Alberta Environment. 1995 & Golder Associates. 2007) except downstream Bonnybrook WWTP (99.88%) and downstream Strathmore WWTP (99.89%). All the non-compliances were predicted in the open-water season. The model was run for 18 years; therefore, if the guideline is not met six times that means once every three years.

Three extra segments were output downstream of Fish Creek to better understand the cumulative effects in the City of Calgary reach: 2 km d/s Pine Creek WWTP (Stiers Ranch station), 2 km d/s Heritage WWTP, and 8 km d/s Heritage WWTP (Figure 8). It is important to note that at 2 km downstream a WWTP the effluent may not be completely mixed. In general, the level of compliance increased downstream Bonnybrook. The segment at 8 km d/s Heritage WWTP can be used to analyze the cumulative effects of the City reach on the dissolved oxygen compliance.

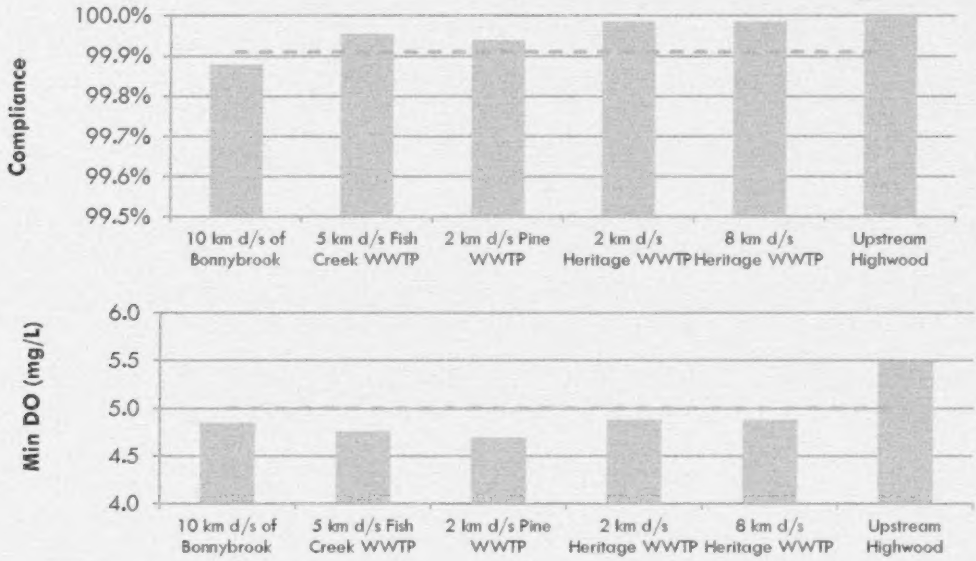


Figure 8. Min DO and acute DO compliance for different locations between Bonnybrook WWTP and upstream Highwood River

Dissolved oxygen compliance in different scenarios

The DO was always above the chronic guideline of 6.5 mg/L (7-day average) at the selected segments (Table 8). The DO was below 8.3 mg/L (7-day average) at least once through May and June for the High diversion and Dry year diversion scenarios. This chronic guideline was in non-compliance in the lower reach (downstream Strathmore WWTP) most often in the area close to Arrowwood Creek.

The acute DO was evaluated for the different scenarios at three critical points: 10 km d/s Bonnybrook, 8 km d/s Heritage WWTP (this location includes the cumulative effects in the City reach), and 10 km d/s Strathmore WWTP. Figure 9 shows the ratio of non-compliance over Base Case for each scenario. For example, the acute guideline would be exceeded 2-fold more often at 10 km d/s Strathmore WWTP for the Forecasted loading scenario. Only one non-compliance event was predicted at 8 km d/s Heritage WWTP (65 km d/s Bearspaw Dam) in the Base Case scenario. The increase of up to 15 times more often

low DO with the Forecasted load scenario suggest that the DO sag zone predicted in the Base Case scenario (Figure 7) may be extended in the future.

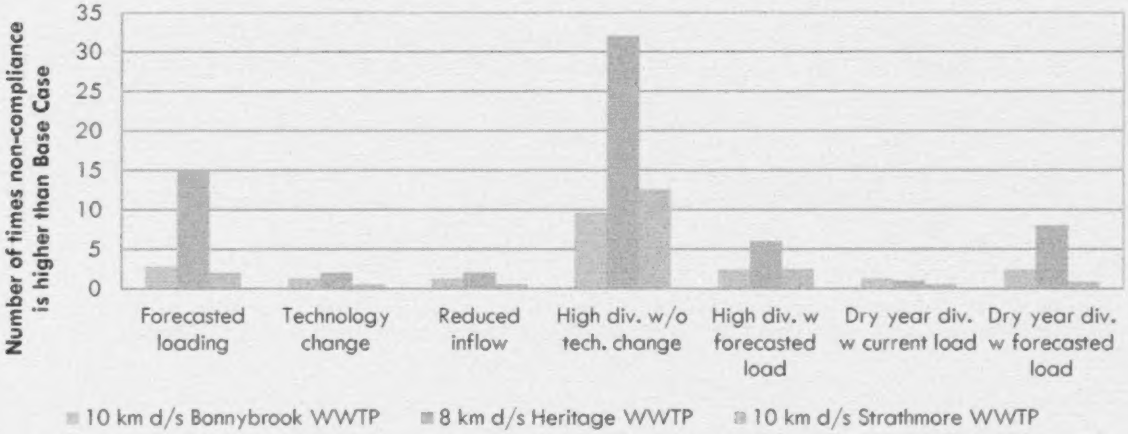


Figure 9. Instances when predicted DO was < 5 mg/L over non-compliance predicted for Base Case

The DO was predicted below the guideline more than six times for all scenarios at 10 km d/s Bonnybrook (six times is the frequency of one every three years). The DO was predicted below the guideline at least once every three years at the three selected locations for the High diversion scenarios. The scenarios using the forecasted loading also had at least six instances with DO below 5 mg/L. Thus, high diversion and the forecasted loading by 2039 suggest increased risk to the aquatic environment.

The frequency of compliance of 99.91% is equivalent to one event in three years. However, as it was computed, it can mean two events in year one and zero events in year two to six. The number of years that the DO was below the guideline varied among locations and scenarios. Figure 10 shows the minimum daily DO observed for each simulated year in the Base Case scenario. Note that this is not the observed minimum DO during each year, but the result of superimposing the loading conditions described in the scenario definition with the flow and weather patterns of past years.

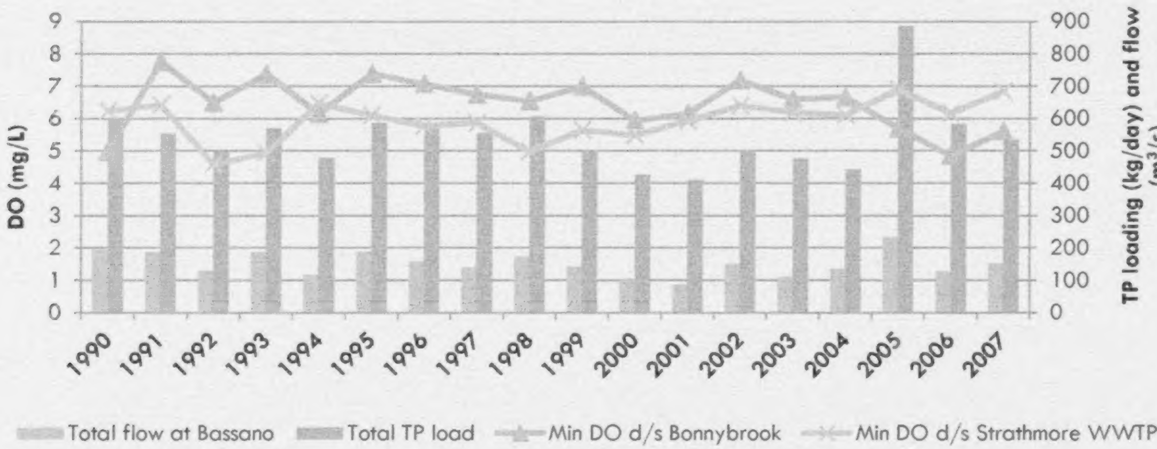


Figure 10. Annual minimum DO, average TP loading and flow for Base Case scenario

For the Base Case, all the non-compliances were predicted under the 1992, 1993 and 1998 flow conditions downstream Strathmore, and under the 1990 and 2006 conditions downstream Bonnybrook. For the High diversion and forecasted loading scenarios, the low DO instances were predicted in six years downstream Bonnybrook (2005-2007, 2000, 2001, 1994), and in nine different years (1992, 1993 and 1995-2001) downstream Strathmore.

5. Conclusions

Overall, the TP and DO concentration predicted did not have a major change using the loading forecasted by 2020 after the Bonnybrook expansion, or with a 10% flow decrease due to climate change. For these two scenarios, the increase in median TP concentration was less than 1% above Highwood River and the acute DO guideline was met a similar number of times as for the Base Case scenario. However, the climate change scenario may be refined in the future to take into account the changes on irrigation/non-irrigation water demand, runoff patterns and air temperature.

The improvements in WWTP technology by 2039 made a substantial difference in the TP and DO concentration predicted by the model. The TP median was increased around 40% by assuming no change in the current wastewater treatment technology and about 10% with technology change above Highwood River. The number of instances that the DO was below the acute guideline was also close to 5 times more without technology change in the three critical areas identified (downstream Bonnybrook, Heritage and Strathmore, Fig. 9).

However, even with these improvements, the risk of increasing the TP concentration and frequency of DO sags may be considerable with the forecasted load by 2039. Under these conditions, the model predicted that the TP median above Highwood would increase by 10% in the open-water season, while the DO would be below the acute guideline of 5 mg/L more often (2-15 times more often as per Fig. 9). These results suggest that further actions may be required to keep the current TP and DO conditions in the river 25 years from now. This may include loading reductions from other sources besides point sources.

The results presented in this report have to be analyzed together with the scenario assumptions. The TP and DO concentration predicted can change if the loadings increase because of new stormwater data or different methodology to calculate the tributaries loading (i.e. non-point source model, regressions, etc.). As new data is available for Highwood River and for the irrigation return flows, the model results can be reassessed. Likewise, after having the updated stormwater data estimated by The City of Calgary and the post-flood bathymetry the model can be recalibrated.

Scenarios that address best management practices (BMPs) can be included in the future by coupling the stormwater model that City of Calgary is currently developing, and/or model results from Alberta Agriculture watershed models. This will help to assess the effect of changes in rural and urban non-point source loading in the main stem.

References

Alberta Environment. 1995. Water Quality Based Effluent Limits Procedures Manual. Edmonton.

Alberta Environment. 1999. Surface Water Quality Guidelines for use in Alberta. Edmonton.

Alberta Environment. 2010. South Saskatchewan Regional Plan, Water Quantity and Quality Modelling Results. Calgary.

Alberta Environment. 2011. Water quality in the Bow River: Water quality modelling of Scenarios to inform a Regional Load Reduction Plan for phosphorus, Draft report. 2011. Calgary.

Bow River Basin Council. 2005. State of the Bow River Basin. Calgary.

CCME. 2004. Canadian Water Quality Guidelines for the Protection of Aquatic Life. Phosphorus: Canadian Guidance Framework for the Management of Freshwater Systems. Canadian Environmental Quality Guidelines.

CPP and Hutchinson. 2013. Bow River Phosphorus Management Plan Water Quality Data Analysis. Submitted to Alberta Environment and Sustainable Resource Development. Calgary.

Golder Associates. 2004. Bow River Impact Study – Phase 1: Model Development and Calibration. Submitted to City of Calgary (Wastewater, Utilities and Environmental Protection). Calgary.

Golder Associates. 2007. Bow River Impact Study – Phase 2: Development of Total Loading Management Targets for The City of Calgary. Submitted to City of Calgary (Water Resources, Utilities and Environmental Protection). Calgary.

Government of Alberta. 2013. Draft South Saskatchewan Regional Plan 2014-2024. Edmonton.

Rood, S. B., Pan, J., Gill, K. M., Franks, C. G., Samuelson, G. M. and A. Shepherd. 2008. Declining summer flows of Rocky Mountain rivers: Changing seasonal hydrology and probable impacts on floodplain forests. Journal of Hydrology, 349:397-410.

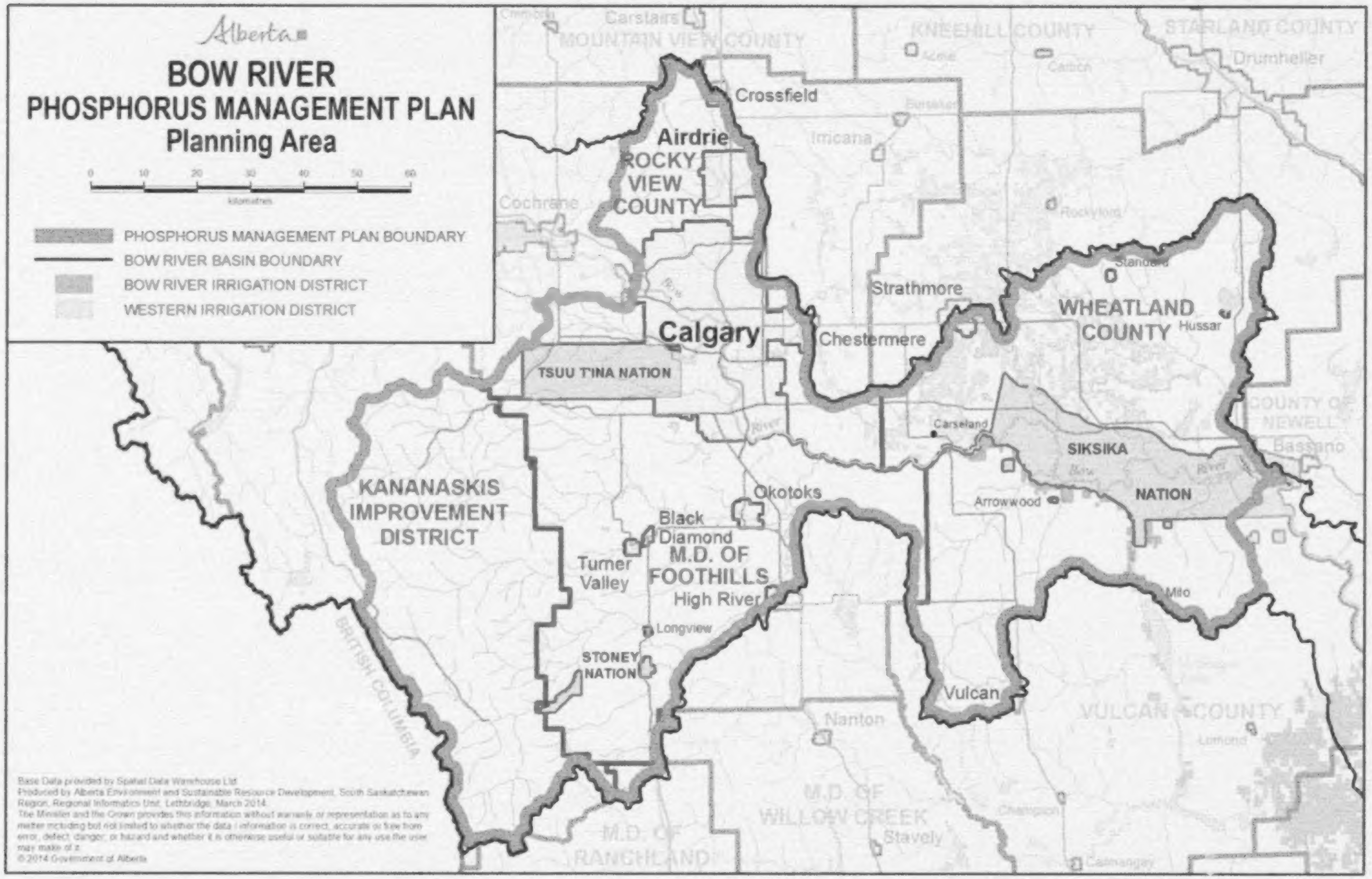
Rood, S. B., Samuelson, G. M., Weber, J. K., and K. A. Wywrot. 2005. Twentieth-century decline in streamflows from the hydrographic apex of North America. Journal of Hydrology 306:215-233.

Tetra Tech. 2013. Bow River Phosphorus Management Plan: Modelling Support for Phosphorus Reduction/Management, Task 2- Model Recalibration and Extension,. Submitted to Alberta Environment and Sustainable Resource Development. Calgary.

Thomann, R. V. and Muller J. A.. 1987. Principles of surface water quality modeling and control. Harper & Row Publishers. New York.

HEC-RAS http://www.hec.usace.army.mil/software/hec-ras/
QHM http://www.scientificsoftwaregroup.com/pages/detailed_description.php?products_id=127
SWAT http://swat.tamu.edu/
WASP http://www.epa.gov/athens/wwqtsc/html/wasp.html

Appendix A. Bow River PMP Planning Area



Appendix B. BRWQM computational grid

The BRWQM is divided in three sub-models (different colors). The concentration is predicted at each cell taking into account the loadings received from different boundary conditions (right descriptors). The model domain includes four water quality monitoring stations.